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Non-pulsing emission from X-ray pulsars

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Abstract. Results of GRANAT/ART-P observations of three X-ray pulsars in non-pulsing states are presented: 1) a statistically significant non-pulsing flux with a simple power-law spectrum was detected during the "off"- state of Her X-1; 2) a significant (13 σ) non-pulsing flux with a strong iron emission line at energies 6.7-6.9 keV was detected during the eclipse ingress of Cen X-3; 3) a weak non-pulsing flux was detected during the X-ray eclipse of Vela X-1, which probably resulted from scattering of the pulsar emission in the stellar wind of an optical star.

1. Her X-1

The "off" state of the X-ray pulsar Her X-1 was observed with the telescope ART-P on board GRANAT three times in 1990-1991. The source persistent flux in this state was detected at the level of few mCrabs (several percents of its high-state flux) and was characterized by the absence of X-ray pulsations — the 3σ upper limit on the pulse fraction in the 3-20 keV band varied between 2.9% and 18% in different observations. The source's "off" state spectra are well described by a simple power law without evidence of a cutoff in the hard energy band or of emission lines. The spectral slopes differ by a factor of ~ 2, with the photon flux in the energy band 3-20 keV being virtually the same. Her X-1 is observed in its "off" state if the compact source is hidden behind the outer edge of a warped (or tilted to the orbital plane) accretion disk and, as it is believed, the source emission can greatly scattered in a hot corona (it's height is $H \geq 10^{11}$ cm) above the outer parts of the disk. Such scattering of emission from the compact source by coronal electrons can account for the existence of an X-ray flux in the "off" state and it allows to explain the absence of pulsations in this state, as any information about variability on a time scale shorter than $H/c \sim 3$ s, where c is the speed of light, must be lost.

2. Cen X-3

A significant declination (by a factor of 6) in the 4-20 keV source flux was detected during the observation on Aug 19, 1990. This declination occurred in two steps, latter of which corresponded to an orbital phase $\phi \simeq 0.89$ at which the X-ray eclipse ingress was observed in other experiments. It is important to note that the intensity decline during the eclipse ingress mainly occurred in the hard energy band and the corresponding hardness (ratio of the 10-20 keV and

4-6 keV fluxes) decrease was equal to $\sim 40\%$. After the eclipse ingress a non-zero and non-pulsing X-ray emission was detected by ART-P from the source at the signal-to-noise level of $S/N \simeq 13\sigma$. The pulsar's spectrum during the eclipse was measured with large statistical errors; nevertheless, a line at energy of ~ 7 keV was very reliable. By assuming that this is the 6.7-keV line of helium-like iron, we estimated its intensity, $I_{6.7} \simeq (2.7 \pm 1.4) \times 10^{-3}$phot$\cdot$cm^{-2}s^{-1} , and equivalent width, $EW_{6.7} \simeq (1.2 \pm 0.6)$ keV. Although the source itself was already occulted by the disk of the optical star at this time, part of the surface of the scattering cloud remained in the visibility zone, and we observed precisely this emission scattered in the cloud. Note also that the measured spectrum at energies below 5 keV shows an excess of soft X-ray emission, which was previously revealed from the light curve analysis.

3. Vela X-1

The observation of this X-ray pulsar on June 15, 1992 (orbital phases 0.918–0.953) was carried out mainly during an eclipse. We divided it into two parts, in accordance with the beginning of the source's eclipse egress. A non-zero flux of approximately 1/10 of the bright-state flux at the confidence levels 4.3 and 4.6σ was observed from the source during the eclipse and eclipse egress, respectively. During the second part of the observation X-ray pulsations with the period $P = 283.33 \pm 1.65$ s were detected from the source at a confidence level of 10.2σ. The pulse fraction was equal to $33.9 \pm 6.4\%$ and it was a factor of 2 lower than one measured in the source's bright state several days earlier. During the eclipse we failed to detect any pulsations — the 3σ limit on the pulse fraction was 9.6%. The persistent flux, detected during an X-ray eclipse, may be the emission scattered in a fairly dense stellar wind or in the extended atmosphere of the optical star. Given that the binary characteristic size, $l \sim a/c \simeq 120$ light seconds, is half the pulsation period, photons must undergo several scatterings for the pulse profile to be smeared enough. For the scattering optical depth of the wind $\tau_{\rm T} \sim 1$, the scattered-to-incident flux ratio allows us to estimate the solid angle $\Omega \sim 0.4\pi a^2$ at which the scattering-envelope ring is seen from the compact source. Accordingly, the envelope height above the optical-star surface is $H \simeq 14 R_\odot$.

More comprehensive discussion of the results of the observations non-pulsing emission from X-ray pulsars with the ART-P telescope are presented elsewhere (see Lutovinov et al. 1999, 2000a,b).

References

Lutovinov, A.A., Grebenev, S.A., & Sunyaev, R.A. 1999, Astron. Lett., 25, 59.

Lutovinov, A.A., Grebenev, S.A., Pavlinsky, M.N., & Sunyaev, R.A. 2000a, Astron. Lett., 26, 691.

Lutovinov, A.A., Grebenev, S.A., Pavlinsky, M.N., & Sunyaev, R.A. 2000b, Astron. Lett., 26, 765.